

338 $\frac{55}{B}$ THE
MECHANIC'S GUIDE:

OR, A

Treatise

ON THE

LAWS OF MECHANICS,

as they relate to

WHEEL MACHINES:

WITH

PLAIN AND EASY RULES TO CALCULATE AND ASCERTAIN THEIR EFFECTS.

ALSO

THE GREATEST POSSIBLE ADVANTAGE TO BE OBTAINED BY SUCH MACHINES, CLEARLY POINTED OUT.

Thereby enabling a Mechanic of common Abilities to comprehend and apply them to any useful Purpose.

BY WILLIAM BIGLAND.

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PREFACE.

HAVING long entertained an opinion, that the laws of mechanics, relating to wheel machines, moved by the power of water, are the least understood of any useful branch of learning whatever; and that nothing stands in so much need of a reform as mechanics, both as to theory and practice; nothing but a sense of my want of abilities to express my ideas with propriety, has prevented me from offering my mite towards their improvement.

But the necessity of a clear and simple investigation of these laws, has at last induced me to undertake the task; and notwithstanding the many disadvantages I labour under, I hope I shall be able so to elucidate them as to be generally understood: if so, I have the vanity to think, that I shall set them (especially as they relate to machines and engines moved by the power of water,) in a clearer light than any other author that has written on the subject; which will be equally to the benefit of the practical mechanic, and the honour of the science.

ERRATA.

Page 4. l. 21. for *stream* r. *depth*—P. 5. l. 5. after *velocity* add by the same power and resistance—P. 10. l. 27. after 100 to 1 add here we must have recourse to two wheels—P. 11. l. 7. for a foot r. 2 feet—P. 12. l. 6. for seconds r. feet—P. 21. l. 22. for bucket r. arm—P. 23. l. 1. for calk r. tub—P. 34. l. 9. for 4th and 5th r. 3d and 4th. [Note, this passage may be passed over to the table, as the same is better expressed in p. 46. from l. 19. &c.]—P. 37. l. 20. for 1:12:6:72 r. 12:1:36:3—P. 48. l. 25. for 3 r. 2.—P. 49. l. 10. for 1:1,5:286:190 r. 1,5:1:286:190—P. 58. l. 4. after axle add of equal diameters—P. 59. l. 9. after water add and consequently mechanic powers in general.

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MECHANIC'S GUIDE, &c.

PART I.

BEFORE we enter on the main object of this work, it is necessary to premise, that the mechanic, if he would arrive at any eminence in his profession, must be acquainted with the common rules of arithmetic, especially with proportion, or, as it is generally denominated, the rule of three. Also, he ought to know something of decimal fractions, for it is impossible for a *millwright* to construct his machines judiciously, without the assistance of these necessary rules. As there is great room for improvement in the construction of mills and machines, I can assure him, that if he is not already acquainted with the use of figures to the extent I have above-mentioned, it will amply repay him immediately to make the necessary acquirement; for without this assistance he must depend solely on the direction of others, and too probably will be led in the dark, to an

erroneous conclusion, as thousands have been before him. With this acquirement, he will not only be able to construct for himself, but to form a deliberate and judicious opinion on the works and labours of others, whether authors or practical mechanics.

As I propose to instruct young mechanics, it will be necessary to explain some abbreviations made use of in this treatise. Two lines, thus $=$ signify equals; a cross $\times$ is the sign of multiplication. *Example*; as $2 \times 2 = 4$; which is to be read, two times two is equal to four. Also in stating the rule of proportion; *example*, as $3:6::6:12$; which is to be read, as three is to six, so is six to twelve; which signifies, that by multiplying the second and third numbers together, and dividing the product by the first number, the quotient, or the last product, is the answer required; as may be further proved by the following *example*; as $2:4::9:18$, and as $5:3::10:6$; or, as $6:9::4:6$, &c.

If the reader knows some little of geometry, it will be an advantage; and the following seems sufficient, as far as relates to wheel machinery:—the outside of a circular wheel is called the *circumference*; and a straight line drawn through the centre, is called the *diameter*; and half the diameter, of the circle or wheel, is called the *radius*.

By the *radiuses* of the several wheels in any machine, I profess to account or deduce their several effects.

To find the diameter or circumference of any circle or wheel, when either is given, the readiest way is to use 1 for the diameter, to which 3,14 is the circumference. *Example*; let the diameter be 6, then as $1:6::3,14:18,84$, the circumference required. But as 1 is the first term in the proportion, it neither multiplies nor divides; therefore by multiplying any wheel's diameter by 3,14, the product is the circumference; and by dividing any wheel's circumference by 3,14, the quotient is the diameter. *Example*; let the diameter be 7, then $7 \times 3,14 = 21,98$ the circumference. If the diameter be 9, then $9 \times 3,14 = 28,26$ the circumference. If 15,7 be the circumference, that divided by 3,14, the quotient is 5, the diameter. If 25,12 is the circumference, that divided by 3,14, the quotient is 8, the diameter requested: all which is so easy, that more examples are needless. I know not that any more of geometry is absolutely necessary, in accounting for the laws of machines; their application and use will be amply shewn in the following pages.

The ratio, or proportional increase, of the mechanic powers may be deduced from the lever, or steelyard, as it is in arithmetical proportion,

as 1, 2, 3, 4, &c. But I hold that neither the lever nor steelyard acts truly, as a mechanic power, in any other position than an horizontal one: hence they are inapplicable to circular motion; therefore we must have recourse to wheels, to supply their defect.

A wheel of one foot radius is of general use in finding the proportions and effects of all wheel machines; but before we can advance to calculation, we must find a true data to proceed from, which will bear the proof of experience. By finding the time and velocity per second of any certain power, and the weight or resistance upon a one-foot radius wheel, we may thereby find all the possible effects of the mechanic powers, by the rule of proportion, as I hope clearly to make appear.

By turning a stream of water on a one-foot radius wheel, sufficient to raise a certain weight, I found, when the wheel had attained a regular motion, it moved with the velocity of 3,14 feet per second; and by doubling the ^{depth} ~~stream~~ of water, it raised the same weight 6,28 feet per second. These data I conclude are true; as nearly so I believe as it is possible to ascertain, exclusive of friction, which in these cases was very little, as three-quarters of an ounce will move the wheel, although its weight is eleven pounds and an half. The above data, and the one-foot radius wheel, is

depth

the foundation from which I principally deduce my calculations.

Before I proceed farther, it is proper to acquaint the reader, that all wheels move with the same velocity, ^{by the same power and resistance,} let their diameters be what they may; and the only difference is, that large wheels being heavier than small ones, cause more friction upon the centre; consequently it retards their motion in proportion. This the artificer ought to have a clear idea of, as it is an essential part of the laws of mechanics, as may be proved by experiment.

This being premised, we will suppose when the power is as 2 to 1, the one-foot radius wheel moves once round in a second, = 6,28 feet; and as all wheels move, by the laws of nature, with the same number of feet per second, this one-foot radius wheel affords us an easy rule to find the velocity of any other wheel per second; also the number of seconds any wheel is in making one revolution. Thus, as one foot is to one second, so is two feet to two seconds:

For the radiuses being	. 2, 4, 6, 8, &c.
The time of 1 revolution is	1, 2, 3, 4, &c.
If we proceed by diameters of	 2, 3, 4, 5, 6, &c.
The time will increase by half-seconds, as	. . 1, $1\frac{1}{2}$, 2, $2\frac{1}{2}$, 3, &c.

Also, by reducing the circumference of the one-foot radius wheel into inches, the product will be 75,36; and by dividing that by the distance we would have the cogs apart, the quotient will give the number of cogs the circumference will contain. I presume 3,8 inches a proper distance; then 75,36 divided by 3,8, the quotient is 20 very near. So that the one-foot radius wheel will contain twenty cogs, at 3,8 inches apart. The practical mechanic may fix upon any other distance he pleases, but I advise him, in all cases, to make the cogs as close as possible, so that they work free of each other; as then they will work truer, wear less, and cause less friction in rubbing against each other. Also, as a one-foot radius is to twenty cogs, or rounds, so is any other wheel's radius to the number of cogs it will contain, at the same distance apart. Again, as twenty cogs, or rounds, is to the radius, so is the number of cogs to any other radius. Thus, suppose we want a trundle of sixteen rounds, then, as twenty rounds is to 12 inches radius, so is sixteen to the radius sought. Thus, as $20:12::16:9,6$ inches, the radius that will contain sixteen rounds in its circumference, at 3,8 inches apart; and as one foot radius is to its circumference 6,28, so is any other wheel's radius to its circumference. *Example*; the radius 4 given, as $1:6,28:4::12,56$. The radius being 6, then as $1:6,28::6:18,84$, the circumference.

By the foregoing rules, the following table is calculated :

Wheels' diameters.	Circumference of the wheels in feet.	Number of cogs in each wheel.	Number of seconds in one turn of each wheel.	No. of turns each wheel makes per minute; found by dividing 60 by the number of seconds each wheel is in going once round.	
4	12,56	40	2,0	30,00	Trundle 2 feet diameter 20 rounds at 3,8 inches apart; velocity 6,28 feet per second. The power supposed double the resistance.
5	15,7	50	2,5	24,00	
6	18,84	60	3,0	20,00	
7	21,98	70	3,5	17,14	
8	25,12	80	4,0	15,00	
9	28,26	90	4,5	13,33	

It must appear evident by the foregoing rules, how easy it is to calculate all the proportions of wheels by the help of this one-foot radius wheel, for as its radius is to all its parts, so is any other wheel's radius to the parts thereof: and as any part of its circumference is to the radius, so is any other wheel's circumference to the radius thereof. And I doubt not but I shall be able to demonstrate that this one-foot radius wheel affords us as easy rules to find the effect of machines, simple or compound, as it does to calculate the proportions of the parts of wheels, &c.



I HAVE already observed, that wheels are the only true levers; and I shall account for the action of all wheel machines, according as the train of the wheels consists of one or more levers, &c.

A windlass is a simple mechanic power, and is well known, as it is frequently made use of to draw water out of wells, and for several other purposes. Let the turn of the handle be 12 inches, and the cylinder that the rope winds round be 3 inches radius, to determine the weight a man will raise thereby, by applying a power at the handle equal to 30 lb. This constitutes a lever as 12 the radius of a two-feet diameter circle is to 3 inches the radius of the cylinder. The rule is, to divide 12 by 3, the quotient is 4; which shews that the power is as 1 to 4 the weight; and by multiplying the power by 4, the product is the weight that the power will equal: thus, $30 \times 4 = 120$. If the weight 120 lb had been given, and the power 30 to raise it, the general rule in such cases, when the weight and power are given, is to divide the weight

* - . , +

$$30 \div 4 = 34$$

$$4 \times 30 = 120$$

by the power, and the quotient gives the proportion the wheel must be to the axle, as 1 is to that quotient. Thus, in the present case, the weight is 120 lb. divided by 30 the power, the quotient is 4; which shews the wheel must be in proportion to the axle or cylinder, as 4 to 1; and agreeable to the weight which is to be raised, the mechanic must adjust his axle accordingly, and the wheel in proportion to the axle, &c.

Example 2.—We will next propose a wheel and axle that a man, by applying 30 lb. to the handle of a one-foot radius, will raise 300 lb. First divide 300 by 30, the quotient is 10, which shews that the radius of the wheel must be to the radius of the axle as 10 to 1. Note, I generally make one foot radius the standard in calculating, which in this case is two feet diameter; then the wheel will require to be 20 feet diameter, or the axle may be 1 foot, the wheel 10; or the axle may be 6 inches diameter; then the wheel will be 5 feet diameter. In each of these proportions, the man will raise the weight in the same time, and nearly with as much ease: but it is the judgement of a mechanic to reduce the axle as small as it will admit of, so it is sufficient to support the weight; in this case we will suppose 6 inches diameter sufficient, then the wheel must be 5 feet diameter; and as 3 inches, or .25 parts of a foot, is to 2,5 feet, so is 30 to 300 lb.;

or as radius 3:30::30:300; that is, as the radius 3 inches is to the radius 30 inches, so is 30 lb. to 300 lb. Observe, I distinguish the wheel, or first mover, in all cases as the first leader, and the axle the first follower; and if there are two or more levers in any machine, I call the first, where the power is applied, the first leader and follower; the second lever the second leader and follower, &c.; by which I ascertain the effect of the machine; all which will be better understood when I come to apply them to the several examples following.

I believe wheels are generally turned by spokes in the circumference, but I think it would be more convenient to have cogs round the wheel, and to be turned by a one-foot radius wheel, fixed at the side of the wheel, with cogs or rounds in it, for a man to turn it by; then 2,5 turns of this two-feet wheel will turn the five-feet wheel once round; and suppose a man turns the one-foot handle once round in a second, he will turn the great wheel once round in 2,5 seconds, and in that time raise the weight 18,84 inches.

Example 3.—Let the power be 30 lb. and the weight 3000 lb. by dividing 3000 by 30, the quotient is 100, therefore the wheel must be in proportion as 100 to 1.[^] First, we must find the two



radiuses, that when multiplied together their product may be 100; thus, $10 \times 10 = 100$; so two wheels multiplying each other will produce the same effect as a single wheel of 200 feet diameter, and an axle of 2 feet diameter.

The wheels having cogs for a man to turn the first or leading wheel, by a ^{wheel 2 feet} ~~foot~~ diameter, with a handle one foot in the turn, as I have already observed, this leading wheel must have a one-foot radius follower upon the same axle, so fixed as to turn the second leading wheel, and this second leader's axle also one foot radius, which is to raise the weight by a rope going round it. The rule to find the effect of any number of multiplying wheels is, to multiply all the leaders into one sum, and all the followers together, and divide the sum of the leaders by the sum of the followers; the quotient is the long end of the lever; and the proportion of the power is to the proportion of the weight as 1 is to that quotient. Thus, in the present example, the two leaders are 10 each, and $10 \times 10 = 100$; the followers being each one foot radius, neither multiply nor divide, therefore the proportion is as $1 : 100 :: 30 : 3000$; and to find the velocity for any space or time, we will suppose the man to turn the handle once round in 2 seconds, the velocity will be 3,14 feet per second. As the man is 2 seconds in turning the handle once

2 feet

round, the proportion is, as radius 1 is to radius 100, so is 2 seconds to 200 seconds, the time of one revolution; and as radius 100 is to 200 seconds, so is 3,14, the velocity per second, to 6,28 feet, the space the weight is raised in 200 seconds; and as 1 second is to 3,14 ^{feet} seconds, so is 200 seconds to 628 feet, the number of feet the handle moves whilst the weight is raised 6,28 feet. By adding a third multiplying wheel of 10 feet radius, then $10 \times 10 \times 10 = 1000$; here the long end of the lever is as 1000 to 1, and by adding a fourth wheel of the same radius, $10 \times 10 \times 10 \times 10 = 10,000$, the long end of the lever to 1 the short end; so that by multiplying wheels, the lever may be increased almost *ad infinitum*. Hence Archimedes' problem is not only possible, but may be put in practice: and no doubt he had this in view when he proposed it; for it is absurd to suppose that so great a mechanic intended a long pole or bar to be infinitely extended.

Here we may observe, that we gain no velocity by lengthening the ends of levers; but the long end has invariably the same velocity of the balance; and whatever velocity the moving force and resisting force gives with the balance, that velocity (let it be 6,28, 3,14, or any other velocity) is invariably the same at the increased end of the lever. The general rule to find the velocity of

the short end, is to divide the velocity found with the balance by the difference of the ends of the lever, and the quotient is the velocity of the short end: for instance, in the following table (p. 17), the velocity with the balance is 6,28, the lever being as 2 to 1; by dividing 6,28 by 2, the quotient is 3,14, the velocity of the short end; the lever being as 3 to 1, 6,28 divided by 3, gives 2,0933, the velocity of the short end, and so of the rest: and to whatever length the lever is extended, viz. 10, 100, 1000, &c. this rule finds the velocity of the short end, &c.

Although we may construct wheels, &c. so that a small power may equal 10,000 times its weight, yet in this case the balance is equal or superior; as a man by a two-feet radius wheel would raise the 10,000 lb. in the same time, with as much or more ease, were the weight so circumstanced, that it might be raised in small detached parts, as a coil of rope, &c.; but as few such cases will occur, to which a balance can apply, we must have recourse to levers as the most convenient method to raise a great weight by a small power; as, for instance, when a man has to raise a weight of ten or twenty times more than his strength, it may not only be necessary to increase, but to multiply the power, as is the case at wharfs and inns, to load and unload ships, waggons, &c. therefore it may

be proper to inform the reader how those sort of machines are constructed.

The machines at wharfs, &c. generally have their wheels made of iron, which admit of being contracted much more than wheels made of wood; and small wheels will have the same effect as large ones, if in the same proportion; for it is the proportion, and not the largeness of wheels that determines the effect; hence all machines ought to be contracted as much possible, so that no part be so small as to cramp the movements of the several parts.—*Experiment.* Let the handle the man turns by, be one foot radius, and a nut or pinion upon the same axle with the handle, suppose 1,5 inches (I think one inch radius is too small); the pinion to turn a second wheel or leader, 6 inches radius, and this second wheel's axle to have a cylinder upon it, for the rope to wind round 3 inches radius, required the effect of this train of wheels, by a power applied at the handle equal to 30 lb. The first leader is the handle 12 inches, the second leader 6 inches, $6 \times 12 = 72$; the first follower is the pinion 1,5 inches, the second follower is 3 inches, $3 \times 1,5 = 4,5$, and 72 divided by 4,5, the quotient is 16; therefore, the two levers reduced into one, the long end is 16, the short end is 1; that is, the effect of those wheels is in proportion as 16 to 1, then as $1:16::30:480$ lb. or $4,5:72::$

30:480 lb. the weight a man may raise by such a machine. Suppose another wheel is added, 6 inches radius, and a nut or pinion 1,5 inches radius; the pinion on the same axle with the handle turning the second wheel; this second wheel's axle having a pinion on it that turns the third wheel; this third wheel with a cylinder on it for the rope to wind round 3 inches radius; required the effect of these three compound levers. To reduce them to a single lever:—the levers are $12 \times 6 \times 6 = 432$; the followers are $1,5 \times 1,5 \times 3 = 6,75$, and 432 divided by 6,75, the quotient is 64; so that the effect of the three levers, when reduced into one, is as 64 to 1; therefore, as $1:64::30:1920$ lb.; or as $6,75:432::30:1920$, the weight which 30 lb. at the handle will be equal to: and to determine the time a man will raise the weight any number of feet per second, we must fix upon a certain velocity of the power per second. If a man turns a two-feet wheel once round in a second, the velocity will be 6,28 feet in that time; but this is too quick a motion for a man to continue for any considerable length of time, therefore by turning the handle once round in two seconds, it will be at the rate of 3,14 feet in one second, which seems the most proper velocity for a man to maintain. Then, as in the last three levers, when reduced into one, the proportion was as 64 to 1; therefore, as radius 64:1; 3,14, the velocity of the power, to .049 parts of

a foot, or .588 parts of an inch, in one second. Hence multiplying the weight so much more than the power is of little use; and I hold, that either to increase the power, or weight to be raised, ought never to be complied with, but when the necessity of the case absolutely requires it.

If by experiment, or otherwise, we know the power and velocity by the balance, we may thereby find the velocity of the short end of the lever, when one end is increased 2, 3, 4, &c. whilst the other end remains the same.—*Example*; let A, in the following table, remain the same, and B be increased 2, 3, 4, &c.; in this case, B will have invariably the same velocity, and by adding 2, 3, and 4 times the weight at A, its velocity will decrease 2, 3, and 4 times; therefore, by lengthening the end of the lever 2, 3, and 4 times, the loss of velocity is exactly equivalent to the weight gained. This is a general law of levers, &c. When A and B is a balance, then we suppose the velocity will be 6,28 feet per second. Suppose a man by turning a one-foot handle apply a power of 30 lb. and the weight at A 15 lb. we will call the power at the handle B.—The weight and velocity will be shewn by the following table:

TABLE II.

A.	B.	W.	P.	Velocity of A.	Velocity of B.	
1	1	15	30	6,28	6,28	The first column in this table, is the radius of the axle A.—The second, is the increasing radius of B.—The third the increasing weights to balance the increase of the radius of B.—Fourth, the power applied at B.—Fifth, the decreasing velocity of A.—Sixth, the invariable velocity of B.
1	2	30	30	3,14	6,28	
1	3	45	30	2,093	6,28	
1	4	60	30	1,57	6,28	
1	50	750	30	0,1256	6,28	
1	60	900	30	0,1046	6,28	

In the foregoing table I chose to take the example from a man turning a handle, that it may be clearly understood. To explain the various effects contained therein, it may be necessary to observe, we suppose the man turns the different radius wheels of B by a wheel of one-foot radius once round in a second, which is equal to 6,28 feet; this velocity is the standard measure of all the proportions. This will be more clearly explained by the following statements. The several proportions are, as the radius of B is to its velocity, so is 1 to the velocity of A.

Thus (when the ends are a balance) as radius
 $1:6,28::1:6,28$
 $2:6,28::1:3,14$

$$3:6,28::1:2,093$$

$$4:6,28::1:1,57$$

$$50:6,28::1:0,1256$$

$$60:6,28::1:0,1046.$$

This I hold is the true law of wheels, axles, levers, &c. and will bear the proof of experiment.

It is common to say, that a lever is as 2 to 1, 3 to 1, &c. ; and that the long end has two and three times the velocity of the short end ; which is true : but to suppose that the long end increases its velocity in the least, by increasing its length (which, I believe, is the general opinion of mechanics) is a most notorious mistake ; it is the short end only that decreases its velocity, the longest radius in all cases represents the balance, which bounds the limit of velocity. If we gain velocity by lengthening the radius of wheels, &c. we gain power, for gaining velocity is in fact gaining power, which is impossible. It is said, as a maxim in mechanics, that in gaining power we lose time, and in gaining time we lose power. The term *gaining power* should be excluded from all treatises of mechanics ; it conveys a false idea, and it is by this idea that many mistakes are committed. I will substitute a maxim in the place of the above which, I presume, is better suited to convey the true idea, viz.—what is gained in weight or resistance is lost in velocity ; and what is gained

in velocity is lost in weight. It may be seen, in the foregoing table, that this maxim only applies to the weight A, the power at B is invariably the same.

Several authors make a parade of finding maximums, or the greatest advantage possible. In all cases of wheels and axles, if the weight and power are given (which is generally the case), by dividing the weight by the power, the quotient is the proportion of the wheel, as that quotient is to one; and this rule generally determines the maximum, or greatest advantage; which I have already explained.



*Of Water flowing through Apertures at different
Depths from the Surface; and its Action on
Wheel Machines, &c.*

EMINENT men in all ages have tried many experiments to ascertain the quantity and velocity of water flowing out at apertures, at different depths from the surface; but scarce two of them agree, which shews the difficulties attending it: and various are the opinions of water acting upon wheels; many of which, I presume, are not only inconsistent, but absurd. But vague opinions prove nothing, I will, therefore, proceed to describe the experiments I have made, and the deductions I have drawn from them.

In order to prove by experiment, whether I was right in my conjectures of the water acting upon wheels, I caused a wheel to be made, the dimensions of which were as follow:—the inside of the rim 1 foot 10 inches diameter, and from out to

out something above 2 feet 1,5 inches; therefore the rim was full 3 inches deep: the float boards all pointed to the centre, which is of more advantage than if they inclined to the wheel, as the water would then have struck them more oblique, whereas when they point to the centre the water strikes them nearer to a right angle: there are 24 floats round the wheel, which I think are too many, and that 18 or 20 would have been of more advantage, as they cut the stream of water too much. I had a circular channel made, to fit one quarter of the wheel, from the horizontal arm to the bottom, so as to enclose one quarter of the wheel, to keep the water in the buckets close. The wheel moved on points or centres, therefore the friction was so little as not to be regarded. The rim of the wheel was 3 inches, and a channel of the same width conveyed the water to the wheel, through a square hole at its bottom; the water through this hole was so disposed as to direct the stream, as near as possible, to strike the middle of the floats, at the horizontal ^{arm} ~~bucket~~. This channel that conveys the water to the wheel must be placed some height above the centre of the wheel; at the other end of the channel was a box of about 9 inches square to pour the water into. The wheel being fixed where there was a perpendicular descent of 10 feet, I caused two men

arm.

to attend with water to supply it therewith.—*Note*, the square hole was the width of the wheel, *i. e.* 3 inches and 1,15 broad, as near as I could determine, the area of which is 3,45 inches, equal to 2 ounces of water: the axle of the wheel was 1 inch radius, and the wheel being a one-foot radius, consequently it was as 12 to 1. I fixed a small cord to the axle, and a weight of 36 ounces thereto, and the men pouring water into the aforesaid box, the weight was raised 10 feet in 25 seconds. I repeated the experiment, and desired the men to supply the wheel quicker with water; but the weight was not raised 10 feet one second sooner than before: and I now found, that this method of supplying the wheel would not determine the effect of water upon wheels, as I observed it moved sometimes quicker and sometimes slower. I was now at a loss how to proceed, as there is neither a running stream, nor other body of water, for miles; but I bethought me of a method which answered my purpose better than I could have expected; which was, by cutting a hole at one head of a 17-gallon cask, about 4 inches square, and fitting a plug thereto; and by filling this cask with water, putting in the plug, and turning it downwards into a tub full of water, with a channel from this tub to direct it to the wheel, which channel I stopped till I was ready to let the water upon the wheel; and by raising the water

in the ^{tub} ~~canal~~ higher or lower, I could make the water in the channel that conveyed it to the wheel at any height I pleased; and I fixed upon 1, 2, and 4 inches depth, they being in duplicate ratio to each other, that I might thereby determine the proportion. I first caused the water to stand at 1 inch depth, took out the plug, fixed a weight of 9 ounces to be raised at the axle, and let the water upon the wheel: it raised the weight 10 feet in 19 seconds. I then set the water at 2 inches depth, and applied a weight of 18 ounces, and this the wheel raised in 19 seconds. I then caused the water to stand at 4 inches depth before I let it on the wheel, which now raised 36 ounces the same distance in exactly the same time. I repeated the experiments several times with equal success: when these were made, I used the circular channel to keep the water close to one quarter of the wheel; I then took it off, and repeated the same experiments with the naked wheel, and the result was exactly the same, there being not one-half of a second difference in 19. This demonstrates that the weight of water in the buckets contributes not a jot towards moving the resistance; but that the wheel is wholly influenced by the momentary impulse and weight of the water at its horizontal arm, when the velocity is 6,28 feet per second: and as a dead weight can only act at the horizontal arm of a wheel, it is evident that water does the same.

tub

I made a fourth experiment, by increasing the weight from 36 to 72 ounces, which I supposed would equal the weight and impulse of the water at 4 inches depth: the wheel raised this weight with the velocity of 3,14 feet per second. Thus the foregoing theory is proved by experiment, *i.e.* that when the impulse and weight of water is equal to the resistance or weight to be raised, the velocity is 3,14 feet per second, and when the impulse and weight of water is double the weight, the velocity is 6,28 feet per second. Hence we deduce the increase and decrease of the mechanic powers, according to the proportion of the power to the weight, &c. As 3,14 is the velocity of 1, or the balance, by multiplying 3,14 by 2, 3, 4, &c. the product is the velocity; thus, $3,14 \times 2 = 6,28$. $3,14 \times 3 = 9,42$. $3,14 \times 4 = 12,56$. But all velocities above 6,28 feet per second will fall short of the computed impediments of the laws of nature, &c.

That this is the true law by which water acts upon wheels, I have not the least doubt; and by finding the velocity of a wheel with a foot deep of water, and 144 square inches area, whatever velocity this body of water may give to the wheel, with a certain weight or resistance opposed thereto, twice the depth will give the same velocity to twice the resistance; and three feet deep, through the same aperture, will give the same velocity to three times the resistance, &c.

From hence we deduce that the same law which governs the mechanic powers, governs the flowing of water through apertures at different depths from the surface, neither of which is governed by the laws of falling bodies in free space. This might be proved by experiments with a wheel and a suitable stream of water. But when we have found the velocity of the wheel per second, this will not determine the effect, or momentum of the water that is employed to move the wheel: I shall prove presently, that the water acts but a very small space of a second upon the wheel, when it moves with 4, 5, or 6 feet per second.

In order to find the effect of the water in turning the wheel, I weighed and measured it, and found the cask I made use of contained 4794 square inches: and from the experiments I have made, may be drawn inferences of the greatest importance, concerning the flowing of water through apertures, at different depths from the surface of a pond, reservoir, &c. as also its effects upon wheels.

By experiment I found the area at 1 inch depth, through a square hole 3 inches wide and 1,15 inch broad, equal to 3,45 square inches; the stream of water was ,530122; and as $3,45:1::,530122:1,5339$, the area of a stream of water that

will flow through a hole 1 inch square, the depth being 1 inch from the surface.

This 1 inch area gives us an easy rule to find the area when the area of an aperture is given.

Rule.—Multiply the number of square inches contained in the orifice given by the area, 15339, the product is the area flowing out at the aperture, when the depth is 1 inch; this product multiplied by any proposed depth, gives the area of the flowing stream at that depth. *Example 1st:* Let the area be 1 inch and the depth 9 inches, then $15339 \times 9 = 1,3805$ inch, the area flowing out of a 1-inch square hole 9 inches below the surface. *Example 2d:* Let the area be 3,456, and the depth 4 inches, as in the third experiment, then $15339 \times 3,456 = 530122$, the area at 1 inch deep, and $53 \times 4 = 2,12$ the area of the stream of water constantly flowing out at the aperture, 4 inches from the surface. *Example 3d:* Given the aperture 6 square inches, the depth 12 inches, $15339 \times 6 = 92034$, and $92034 \times 12 = 11,04408$, the area constantly flowing through a 6-inch hole, 12 inches below the surface. *Example 4th:* The area 1 foot square, or 144 square inches, $15339 \times 144 = 22,088$, which being multiplied by any number of inches, suppose 12, $22,088 \times 12 = 265,056$, the area of the flowing water. *Example 5th:* Let

the area be the same as the last, and the depth 6 feet, in the last example the area is found to be 265,056, and 265×6 the product is 1590,336 square inches; the area of the flowing water through an aperture 144 square inches, and 6 feet below the surface.

By the same rule may be found the quantity, or area, of a column of water flowing out at any given depth and opening from the surface.

By dividing the number of square inches issuing out of any aperture by 1,728, the quotient is the number of ounces, which divided by 16 gives the number of pounds. Thus, in the 15th example, the area is 144 square inches, and 6 feet deep, the area or column of water constantly flowing out at the aperture is 1590,336 square inches; and I find by experiment the impulse and weight of water upon a wheel is nearly equal to 4,89 times the column of water; and $1590,336 \times 4,89$, the product is 7776,743, which divided by 1,728, the weight of 1 ounce of water, the quotient is 4494,6, this sum divided by 16, the quotient is 280,9 pounds, the weight and impulse of the flowing water upon wheels. By the same process may be found the impulse and weight of water acting upon wheels of any other depth and apertures, &c.

I have many years been clearly of opinion, that the action of water upon wheels, was but of short duration, and might be properly said to act by momentary impulses; but I ever despaired to find it out by rule, till I made a few experiments; by which I find the time of its action upon a wheel is limited to something less than $\frac{1}{5}$ - $\frac{1}{60}$ of a second. I also find in the area of water flowing through apertures, that the column of water only fills a proportionaal part of the area, till it is 6,52 inches deep, when the column of water and area of the aperture become equal, and at about 13 inches deep the column becomes double, and at $19\frac{1}{2}$ inches deep the column is three times the area of the aperture, &c. What will the learned critics say to this new doctrine, so widely different from any established theory? So different, that I can scarcely trust my own conclusions, as it seems almost impossible that so many eminent men, by almost innumerable experiments, should none of them hit upon the true law of flowing water at different depths from the surface, &c. It seems to me, they were all misled by conceiving that the same law which governs falling bodies, also governs the flowing of water at different depths from the surface of ponds, &c.; and rather than endeavour to find out any other law to account for it, tacitly believed it was the same, and therefore endeavoured to find out plausible reasons to account for the great dif-

ference between theory and experiments; not considering it is scarce possible there should be so great a disproportion as 5 to 8, between experiments and true theory.

I find by the experiments I have made, that the progressive increase of water flowing out at apertures, at different depths, is not according to the square root of the depths, but at 1 inch a certain quantity, at 2 inches twice that quantity, at 3 inches three times that quantity, and so increasing in arithmetical progression to any depth proposed, as I have shewn in the foregoing examples.

This law seems more consistent with sound reason, than to suppose that water is governed by the same laws as falling bodies in the air; we will allow that it flows towards the openings, or apertures, in a perpendicular direction, but it has to make its way through a much grosser fluid than air, consequently must meet with a proportionable obstruction.

It is also agreeable to sound reasoning that it increases according to the foregoing ratio. What is the cause of its increasing quantity, according to the increase of depth, but the additional pressure of the water above? And is not this increase of pressure uniform, viz. 1 foot, 2 feet, 3 feet, &c.?

And is it not consonant to reason, that an equal uniform increase of pressure should cause an uniform increase of quantity flowing, &c.? This, in my opinion, has much more probability in its favour, than that the laws of accelerated motion should influence the flowing of water at different depths.

The experiments I have made, plainly indicate that the velocity is the same at all depths, viz. 6,28 feet per second. To prove from these experiments that the velocity of water is the same, through equal apertures, let the depth be what it may; and that it is not the length of the column of flowing water, but the area of the column which increases according to the depth.

Example 1st. The area of the aperture, in all the experiments, was 3,45 square inches; in this case the depth of water 1 inch, the quantity was 4794 square inches, the time of its running out 120 seconds. The area found by the foregoing rule is ,530122 square inches, 75,36 inches (the number contained in 6,28 feet) multiplied by ,530122 the product is 39,94992392, from which we may conclude, that the 4 in the hundred parts may be estimated as 5, the sum will be 39,95; and $39,95 \times 120$, the number of seconds the water was in running out, the product is 4794, the exact

quantity of water run out: hence it is an incontestable proof, that the water flowed out of the aperture 6,28 feet per second.

In the 2d experiment the water was 2 inches deep, the time of running out 60 seconds, the area of the running stream, found by the foregoing rule, is 1,060244; $1,060244 \times 75,36$, the product is 79,89998784, the square inches per second; this sum multiplied by 60, the number of seconds it was in running out, the product is 4793,9992704. *Note*, it is of no use to run such great lengths into decimals, because our senses cannot distinguish such minute parts; hence I shall only take the hundred parts in future calculations, except the third decimal is above 5, which I think is sufficiently exact, except in exceeding nice calculations, which I think this subject does not require.

Experiment 3d. The depth of water 4 inches, the area is found to be 2,12 of flowing water, the time of 4794 inches running out 30 seconds: $75,36 \times 2,12$ the product is 159,7632, the square column of flowing water $159,7632 \times 30$ the product is 4792,896. Here the quantity falls short above a square inch: this does not invalidate the truth of the rule, as it is owing to the imperfection of decimals.

I made a fourth experiment, which affords something very singular from the foregoing: the water was at the same depth as in the third experiment, viz. 4 inches, and the resistance in that case was 36 ounces; but in this it was 72 ounces, supposed to be equal to the impulse and weight of water flowing when the water is at 4 inches. This impulse and weight of flowing water being only equal on a balance to the resisting weight, it therefore collects in the channel that conveys the water to the wheel, till it overcomes the resistance, and rises nearly to double the height to what it was in the channel in the third experiment; when the motion of the wheel becomes regular, its velocity is 3,14 feet per second; but the velocity of the flowing water was 6,28 feet per second, as is proved by the following calculation:—first, it is to be noted, that the water rises twice the height in the channel to what it was when the resistance is but half; hence it is equal in pressure, as if the water were 8 inches deep, the area of the flowing water is 4,24: $4,24 \times 75,36$, the product is 319,5264, which multiplied by 15 seconds, the time the 4794 square inches was in running out, the product is 4792,896.

This fourth experiment enables us to discover the great effect of the impulse of water upon a

wheel, when applied to the greatest advantage. In the 3d experiment the water being set at 4 inches depth, gave the wheel the velocity of 6,28 feet per second, with a resistance of 36 ounces at the axle: but by doubling the resistance to 72 ounces, the water rises to double the depth in the channel to what it was when the resistance was 36 ounces, and the column of water flowing upon the wheel is 4,24, which before was 2,12 square inches; yet this double quantity of water only gives the wheel the velocity of 3,14 feet per second.—Example 5th: by increasing the depth of water to 8 inches, the column of water gives the wheel the velocity of 6,28 feet per second, with a resistance of 72 ounces at the axle; yet the column of water flowing upon the wheel is only 4,24 square inches. Hence we find a notable difference of water acting upon wheels under different circumstances. In the 4th experiment, the water rising in the channel to double the depth it was before, supplies the wheel with twice the quantity of water in the same time, viz. 12 ounces; and as $12:1::72:6$ ounces. This 12 ounces power, with a resistance of 6 ounces, gives the wheel but 3,14 feet per second; yet by doubling the depth of water to 8 inches, the same quantity of water only flows upon the wheel in the same time, yet it gives the wheel double the velocity. As the quantity of water in each case is exactly the same, it is manifest that

F

*2nd Does not twice the Quantity
of Water flow out in the same time*

the double velocity of the wheel is wholly owing to the increased impulse of the water, and not a jot to its weight. Hence the impulse of water upon wheels, when properly applied, is far greater than any author seems to have thought of, and therefore makes it appear, that all the opinions they have set forth of water acting upon wheels, are not founded in truth.

3^d and 4th.

From the ^{3^d}~~4th~~ and ^{4th}~~5th~~ experiments, we are enabled to make a tolerable estimate of the great impulse of water upon wheels. In the 3^d experiment, the column of water was 2,12 square inches, the weight of 1 inch in length is 1,226 ounces; but the impulse and weight are 6 ounces, and 1,226 taken from 6, the remainder is 4,774 ounces the impulse of the water, which is above $\frac{3}{4}$ more than the weight: and if we take 2 inches in length the impulse will then be considerably more than the weight. I am of the opinion, that in the 3^d experiment, the impulse is $\frac{3}{4}$ more than the weight of the water; but then the power must be to the resistance as 2 to 1, or upwards; else this great impulse will not take place, for water acts upon wheels very differently under different circumstances, as I shall shew at large in the third part. This great impulse of water will scarcely meet with credit; but in the third part I shall describe the few mills in America, which are moved solely by

the impulse of the water ; and their great effect will corroborate with the above, and abate the wonder which this may excite.

The following table is calculated by the foregoing rules, deduced from experiments, for the benefit of those who may not be able to calculate.

TABLE III.

Depth in feet.	Dimensions of the area.	The impulse & wt. of water acting upon the wheels in lbs.	Depth in feet.	Dimensions of the area.	The impulse & wt. of water acting upon the wheels in lbs.
1	24 by 6	47.	1	48 by 6	95.
2		95.	2		190.
3		143.	3		285.
4		198.	4		380.
1	24 by 9	68.	1	48 by 9	140.
2		136.	2		286.
3		204.	3		429.
4		272.	4		572.

Note, by doubling the depth, or areas, the number of pounds will be double : or by dividing any of the depths or areas, the number of pounds will be in proportion to the depths or areas so divided. By which it may appear, that it makes no difference whether the depth or area be doubled ; but there is a material difference, for a double area will require twice the quantity of water that doubling the depth will require.

It appears by experimennts, that the flowing of water through apertures of different depths, is in direct proportion to the depths and square inches of the apertures: but the velocity or length of the flowing stream, is invariably 6,28 feet per second in all the experiments; and it is the increase of the column of water, that momentarily flows through the apertures, which causes the increase of the quantity according to increasing depth, or preffure of water above the orifice.

Although I affirm, that water flows out at an aperture 6,28 feet per second, it is not to be understood that I mean the column of water flows the length of 6,28 feet in a second; but that the velocity at the area (viz. 1 inch in length) flows at the rate of 6,28 per second. For as soon as it quits the opening it is retarded, both by the resistance of the air, and its natural tendency to descend by its weight, according to the laws of projectiles. There is no doubt but water, like all other ponderous bodies, will descend by its weight, when in free space; but this is not the case of water acting upon wheels.

It is proved by the 3d experiment, that the velocity of water at the aperture is equal to the velocity of the wheel, which is 6,28 feet per second, but the impulse and weight of the water at the horizontal arm of the wheel continues to act upon

it but a very small space of time; I compute it not more than 4-60 of a second, as I shall make appear by the following statement, in experiment the 3d.—4794 square inches of water, run out at an aperture 3,45 square inches in 30 seconds, the water standing upon a level at 4 inches deep before it was let upon the wheel.—4794 divided by 30, the quotient is 159,8, this number of inches carried the wheel once round in a second, and by dividing 159,8 by 75,36 the number of inches in the circumference of the wheel, the quotient is 2,120475, the area of the stream of water 1 inch in length, at the aperture; and by multiplying this area by 5 the product is 10,602275, this divided by 1,728, the weight of 1 ounce of water, the quotient is 6,1 ounces, a little above twice the resistance.

The weight at the axle 36 ounces, and the power at the wheel 6 ounces, the radius of the wheel 12 inches, and the radius of the axle 1 inch, the proportion is as $\frac{12}{1} :: \frac{36}{6}$; hence the power is to the weight as 2 to 1. From which it appears, that the area of the flowing water acts upon the wheel not more than 5 inches in length, exclusive of the impulse, which must contribute towards turning the wheel: but as it is difficult to determine how much the impulse may amount to, we may with certainty conclude, the weight and impulse conjointly did not act upon the wheel more than 5 inches in length of the area, and not more than

4-60 of a second of time. The rest of the experiments may be proved by the same process.

I have given this explanation to shew by what means I account for water flowing out at apertures 6,28 feet per second; and any one may, by the same experiments, find that what I advance is fact, if he pursues the same process that I was necessitated to make use of, viz. what may be called a perpetual fountain, by turning a 17-gallon cask full of water into a tub of the same, to supply the want of a stream or body of water.

Note, I tried experiments with small tubs, in the bottoms of which were holes, and found that the quantity of water was short of the foregoing experiments, which I attributed to the collateral and various directions in which it endeavoured to arrive at the opening, as it thereby caused a confused and agitated obstruction in its passage. But in the foregoing experiments the water was confined in the channel to the width of the area, so as to run in a parallel direction to the opening, and to flow directly through it; thereby, in some measure, producing the effect of water passing through a short tube, viz. an acceleration of its motion; and, I presume, occasioning the difference in quantity of the tub and close channel.



Of constructing Wheel Machines, &c. to the greatest Advantage; also the applying Water to Wheels; with Rules to find the Power, Velocity, and Effect of Water upon Wheels, deduced from actual Experiments.

THE following rules are deduced from the 3d and 4th experiments, in the second part; where it is proved, that when the moving force of the water is equal to the resisting force, the wheel moves with the velocity of 3,14 feet per second; and when the force of water is twice the resisting force, the wheel moves with the velocity of 6,28 feet per second. I find, by the 4th experiment, that when the natural flowing of the water, at 4 inches depth, by the 3d experiment, viz. 2,12 inches, is a balance to the 72 ounces in the 4th experiment; and if the weights were dead weights, neither would preponderate: but water meeting

with a resistance that exceeds its natural weight and impulse, collects till it overcomes the resistance; as was the case in the 4th experiment, in which it rose to double its former height, and gave the resistance of the 72 ounces 3,14 feet velocity per second: we therefore find that 3,14 is a general mean between the power of water and the resistance, viz. by dividing the power by the resistance, then as the resistance is to 3,14, so is the power to the velocity: thus the power being 2, and the resistance 1, then as $1:2::3,14:6,28$ the velocity; also, as $2:6,28::1:3,14$; and as $1:3,14::1:3,14$; consequently by making 1 the first term, 3,14 the second, and the power the third, the fourth proportional will be the velocity of the wheel, let the power and resistance be what they may. The following examples will make it plain; and will not only find the velocity of the wheel, but also the power and resistance. When any two of them are given, 3,14 is always one of the terms.

CASE 1.—The moving and resisting force given to find the velocity.—*Rule*; multiply the power by 3,14, and divide by the resisting force; the quotient is the velocity.

Example 1st: the power given 200, and resistance 100, what is the velocity? As $100:3,14::200:6,28$ the velocity.—*Example 2d*: the power

given 100, and the resistance 80, what is the velocity? As 80:100::3,14:3,92 the velocity.

Example 3d: the power given 300, and the resistance 200, what is the velocity? As 200:300::3,14:4,71 the velocity required.—By this rule may be found the power and resistance promiscuously given.

CASE 2.—The power and velocity given to find the resistance.—*Rule*: multiply the power by 3,14, and divide by the velocity; the quotient is the resisting force.

Example 1st: the power given 100, and the velocity 5, what is the resistance? As 5:3,14::100:62,8, the resistance.

Example 2d: the power given 150, and the velocity 7, what is the resistance? As 7:3,14::150:67,85 the resistance.

Example 3d: the power given 200, and the velocity 9, what is the resistance? As 9:3,14::200:69,777 the resistance.

Example 4th: the power given 90, and the velocity 14, what is the resistance? As 14:3,14::90:70,65 the resistance.

Example 5th: the power given 400, and the velocity 6,28, what is the resistance? As 6,28:3,14::400:200.

CASE 3.—The velocity and weight, or resistance, given to find the power.—*Rule*: as 3,14 is to the velocity, so is the resistance to the power.

Example 1st: the resistance given 150, and the velocity 4,71, what is the power? As 3,14:4,71::150:225 the power.—*Example 2d*: the weight given 50, and the velocity 5, what is the power? As 3,14:5::50:79,966 the power.—*Example 3d*: the weight given 100, and the velocity 1,57, what is the power? As 3,14:1,57::100:50 the power.
Example 4th: the weight given 40, and the velocity 6, what is the power? As 3,14:6::40:76,43 the power.

We may observe that 3,14 is the general mean proportional between the resisting force and moving force; and by dividing any power by the resistance, the difference is the first term, 3,14 the second, and the power the third; the fourth proportional is the velocity.

Example: suppose the power 200, and the resistance 100; here the proportion is as 2 to 1; then as 1:3,14::2:6,28 the velocity. Let the power be 150, and the resistance 100; here the proportion is as 1 to 1,5; and as 1:3,14::1,5:4,71 the velocity.

From which we deduce a general rule to find the velocity of any proposed power of water acting upon wheels; for as 1 is the first term of the proportion, by multiplying the given or proposed

power by 3,14, the product will be the velocity : by which the following table is calculated, increasing by one-fourths.

TABLE IV.

As the resistance 1 is to	Power	Velocity	As the resistance 1 is to	Power	Velocity
	25	585		2,25	7,056
	5	1,570		2,50	7,850
	75	2,355		5,75	8,635
	1,00	3,140		3,00	9,420
	1,25	3,925		3,25	10,205
	1,50	4,710		3,50	10,990
	1,75	5,492		3,75	11,775
	2,00	6,280		4,00	12,560

By making the maximum the first term in the proportion, its velocity the second, and the resisting force the third, the result will be the same. Thus, as 2 the power is to 6,28 its velocity, so is any other power to its velocity. As $2:6,28::25:7,85$ the velocity; as $2:6,28::1:3,14$; as $2:6,28::1,5:4,71$ the velocity. But by making 1 the general resistance, we need only multiply the powers by 3,14, and the product is the velocity; which is a much shorter process.

Thus we can calculate velocity to any extent we please; but we can carry it to no great length in practice, because the laws of nature prevent it. The friction on the centre, and the resistance of the air at the circumference, both increase with

the velocity; so that velocity is the cause of its own limitation, and not the laws of falling bodies, as is generally supposed. A power of 6 to 1 of resistance, the velocity would be 18,84 feet per second: and a power of 8 to 1 resistance, the velocity would be 25,12, if not prevented by the above-mentioned impediments. But our reason tells us, such violent velocities are impracticable; and if they were practicable, the friction at the centre would set the machine on fire.

From the foregoing table of the action of water upon wheels, we may draw deductions of the utmost importance. The first and most material observation is, that when the power is to the resistance as 2 to 1, and the velocity 6,28, the water acts upon the wheels to the greatest advantage possible; and may be called the maximum of water thus acting, as in fact it is: but this will not be the case except under particular circumstances.

Mechanics, I suppose, will conclude, that when water is let upon the wheel of double the weight of resistance, the wheel will acquire this velocity of 6,28 feet per second. This supposition seems to mislead all mechanics, as it has heretofore myself; but water will not produce this velocity except under certain circumstances. The 4th experiment proves, that double the weight of water

in that case, only gives the wheel the velocity of 3,14 feet per second; but by doubling the depth of water, the same weight of water gave the wheel 6,28 feet per second: hence it is not the weight, but the impulse of the water, which principally governs the velocity of the wheel.

But the great advantage of the impulse of water will not take place, unless the depth and column of water be particularly adapted to bring about the maximum; for it is limited to certain circumstances. When the power of water is to the resisting force as 2 to 1, and the velocity is 6,28 feet per second, we have a particular right to call it the maximum, from its superior advantages to all the other proportions and velocities in the table, under or less than the maximum; all of which will require more water per second to procure their velocities than the maximum, although the same resistance is opposed to each.

The best informed mechanics generally conclude, that the maximum of water acting upon wheels, is when the wheel moves with one-third of the velocity of the flowing water, and the power is to the resistance as 9 to 4; then they conclude the machine is in the greatest perfection.

That they are generally mistaken, I can prove by experiments, which I have repeatedly done.

By the impulle and weight of water being as 2 to 1 of the resistance, and the power being 9 to 4, the proportion is as 2,25 to 1; therefore as 2:6,28::2,25:7,065 feet the velocity. This I can prove by experiment, by adjusting the water so as to have the greatest effect upon the wheel; I believe I can also order it so, that the same stream and area which caused the velocity of 7,065 feet per second, shall only have the velocity of 2,093 feet per second, although the weight of water shall be in this case about three times as much as when the velocity was 7,065 feet per second. This will be looked upon as a paradox, and will scarcely be credited; but the great variety of the flowing of water through areas from different heights, and effects upon wheels, will afford several causes as strange as the above, which former authors seem to have had no idea of, and I have therefore a just right to the first discovery.

From the 3d experiment we may find the proportion of the impulse to the weight of water acting upon wheels, when the effect is a maximum. The area or stream of flowing water was there 2,12049, and the impulse and weight conjointly was 10,368 square inches, equal to 6 ounces in weight, acting upon the wheel; and the weight of 2,12049 inches of water is 1,227 ounce, and 1,227 taken from 6 ounces, the remainder is 4,773 ounces the impulse; by which it appears the im-

pulse is to the weight of water acting upon the wheel nearly as 4 to 1.

By inspecting Table IV. we may observe, that by receding from the maximum of 6,28 velocity, we gradually lose velocity; and when we come to 3,14 the water accumulates in the channel to twice the depth it was at when the velocity was 6,28; and although the water supplied the wheel with double the weight of the resistance, it only gave the wheel the velocity of 3,14 feet per second: here it is evident that half the impulse is lost, and double the weight of water instead thereof:—and at ,785 velocity we lose nearly the whole of the impulse, and in its place four times the quantity of water; and as water has but about one-fourth the power of impulse, the loss of velocity is obvious.

Here we discover a notable difference between a power of water and other powers: with the wheel and axle we gain weight to compensate the loss of velocity; but in the table we discover, by receding from the maximum we exchange impulse for water, which has not more than one-fourth of the power of impulse, when applied to the greatest advantage.

Note, when the velocity of wheels is 6,28 feet per second, it appears, by all the experiments I

have made, that the flowing water and the wheel have exactly the same velocity; and I believe I could, with a convenient situation of water, so order it that the same stream of water and area should produce all the velocities contained in Table IV. under 6,28. In short, I find such a variety in the effects of water upon wheels, as is sufficient to excite wonder, and is scarcely creditable; but as the work is put to press I must haste to finish what I have further to add.



The Utility of Tables III. and IV.

THE ingenious mechanic, before he sets about constructing a machine, ought to fix or determine, as near as he can, the velocity necessary, according to the use it is intended for: and he ought also to consider what resistance the machine will give, that he may proportion the power accordingly. Suppose he would have his machine to move with the velocity of 6,28 feet per second, look in the table (No. III.) for the number of pounds he may judge proper for his power, suppose 285; in the last column of the table, and in the next column, to the left, is 48 inches by 9 for the area; and in the column under depth in feet, he will find the number 3 for the depth; then take half $286 = 143$ for the resisting force, which is as 1 to 2:—this

depth and area will give the machine the velocity of 6,28 feet per second, abating for friction, which in general is not near so much as is imagined; mechanics find many ways to cause resistance, exclusive of friction, &c.

Suppose the mechanic would have his machine move with 4,71 feet per second, then the power to the resistance must be as 1,5 to 1; let the same power 286 be the number of pounds, then the depth and area will be the same; and as $1.5 : 1 :: 286 : 190$

$286 : 190$ the resisting force: the moving force to the resisting force is as 286 to 190; the depth 2 feet and area 48 inches by 9 will give the machine the velocity of 4,71 feet per second.

Suppose the velocity 3,14 feet per second, the depth, power, and area the same. In Table IV. over against 3,14 is as 1 is to 1, which shews the moving and resisting force to be equal, or a balance to each other; therefore 286 power, and the same resistance, will have the velocity of 3,14 feet per second, and all these three different velocities have the same depth and area. Therefore by fixing upon any velocity in Table IV. the proportion of the power to 1, the general resistance in the table, is shewn at the left hand, over against the velocity; and I have shewn above how to proceed with any

velocity, and the proportion, power, and resistance, corresponding thereto.

Note, the foregoing rules and observations will not apply to any machines but those constructed with balance wheels, &c.

To apply Water to Wheels to the greatest Advantage.

Fix the centre of the wheel 16 or 18 inches below the bottom of the channel which conveys the water to the wheel, the channel to be the width of the inside rim of the wheel, and depth in proportion to the quantity of water it has to convey.

Let the bottom of the channel have an opening next the wheel, as wide as the wheel, and 6, 8, or 10 inches broad, more or less, as the case may require; let a board be fixed from top to bottom of the channel, next the wheel, and close to it; this board will be on one side, next the wheel, of the square opening for the water to flow through, and must incline a little to direct the water to strike the float-boards in the middle, as near as may be at the horizontal arm of the wheel; let the floats be 15 or 16 inches apart, and pointing to the

centre of the wheel, which will be of more advantage than if they inclined to the wheel, because then the water would strike them more oblique.

The mechanic is to observe, the whole intention of this contrivance is to direct the water to strike the floats as near as may be at right angles, at the horizontal arm of the wheel, by which the water will have the greatest advantage possible.

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*Of the Size of Wheels, &c.*

I PRESUME why large wheels still prevail, is by supposing that the greater weight of water upon the wheel the greater power; this is proved by the foregoing experiments not to be the case, and that a breast wheel, and the water applied to the greatest advantage, will have nearly double the power of any over-shot wheel, with equal advantage of water. Another reason why large wheels prevail is by supposing, that by lengthening the lever we gain power: this is also vague and imaginary; and is what misleads both mechanics and mankind in general. Levers can never be introduced into a train of wheels but to disadvantage; their whole action, as a mechanic power, proceeds from their being artificial balances, and whatever weight is

gained thereby, an exact equivalent in velocity is lost; and velocity is the most essential thing to be regarded in wheel machines: hence levers ought to be excluded from wheel machines as much as possible.

As the weight of water in the buckets may be proved of no use, when the velocity is 3,14 and upwards; nor the supposed advantage of the gravitating force of the water passing through the half-circumference of the wheel, nor the lengthening of the radiuses of the wheels, is of any advantage; it is evident that large wheels only add weight and friction, without giving any additional power: therefore it is clear we gain advantage by contracting the wheels of machines, as much as the case will admit; as the effect of wheels depend not upon their size, but their proportion, &c. This contraction depends much on the power to be applied: if a man's strength, it admits of the greatest contraction, for he may exert his strength to the utmost advantage, by turning a 12-inch handle; if the power is a horse, we cannot apply his strength but to the greatest disadvantage, because he requires so great a circle to walk round: if a power of water, the wheels may be 2, 3, 4, or 5 feet radius, according to the resistance. But I believe a four-foot radius wheel is large enough for any purpose whatever; a two-foot radius wheel may do in

many cases, when the resistance is not great; and a three-foot radius wheel is sufficient for a mill to grind corn with one pair of stones. In all cases we should be careful to proportion the rim of the wheel to the required quantity of water.

By small wheels we gain many advantages, as they require less timber, less labour, are stronger, and, above all, the convenience of erecting a mill in almost any situation, as they require but a small fall; whereas large over-shot wheels can only be erected where there is a great fall, and are often attended with a heavy expence, and considerable labour.

As to the proportioning of wheels I have nothing to add, as I have all along endeavoured to inculcate, that a water and cog wheel of equal radiuses and a one-foot trundle, is the greatest advantage that the laws of the mechanic powers will admit of; as the power is conveyed from the water wheel to the resistance at the trundle, without abatement, except the friction; and if the resistance acts at the same distance from the centre with the trundle, viz. 1 foot radius, the power and resistance will be equal, or a balance to each other. But this may seldom or never be exactly the case; and if the resistance be more than 1 foot from the centre, it will act as a lever against the

power. For example; in a mill to grind corn, the corn gives no resistance at the centre, but increases all the way to the circumference; hence we cannot take the mean resistance at less than two-thirds the radius of the stone; this constitutes a lever against the trundle; and if the mill stone is 5 feet diameter, the resistance against the trundle will be as 20 to 12; yet we cannot make the trundle larger or smaller, to gain any advantage: suppose we make it 20 inches radius, the power and resistance will be a balance; but to carry the mill stone once round in a second, the velocity of the wheels must be 10,416 feet in a second; for as  $12:20::6,28:10,416$ : on the other hand, if we lessen the trundle to 6 inches, it will increase the resistance double; and, although 3,14 feet per second will move the mill stone once round in a second, yet it requires twice the quantity of water, as is proved by the 4th experiment. Hence a one-foot radius wheel or trundle, is the maximum of wheel machines. In Table IV. all the proportions of the powers and resistances act at equal distances from the centre, consequently a balance to each other; but in this case of the mill stone giving a resistance as 20 to 12, the lever causes a great disadvantage; suppose the power 200 lb. and the resistance 100 lb. if the power and the resistance acted at equal distances from the centre, the 200 lb. power would give the velocity of 6,28 feet



per second, with the 100lb. resistance. But as  $20:12::6,28:3,768$  the velocity that 200 lb. will give when the resistance is as 20 to 12; yet the velocity required is 6,28, therefore as  $3,768:6,28::200:331$  lb. the power required to give 6,28 feet per second, when the resistance is as 20 to 12; and so for any other power and resistance.

The description of a saw-mill wheel in America, which is moved wholly by the impulse of the water, will abate the wonder that the great impulse I have given to water, may excite in the learned mechanic.—This saw-mill was near to where I lived several years, and which I have often contemplated with admiration, considering its simplicity and great effect. The wheel was about 2 feet radius, and its width 4 feet; the water flowed upon it from the height of 5 or 6 feet above the wheel, from a large reservoir; the float-boards were about 9 or 10 inches wide, all pointing to the centre; the middle of the wheel quite open, and had no buckets; the crank which worked the saw, was the same radius as the wheel, consequently a balance; the frame of the saw moved up and down in a frame, without any rollers to ease the rubbing; the logs to be sawed were confined to a frame which dragged along the floor, some of which were 16 or 20 feet long, and 12 or 14 inches square: with all this resistance, this little four-feet

diameter wheel moved with the velocity of 7 or 8 feet per second, which was caused by the momentary impulse of the water; for as soon as it had struck the wheel it flew off in a thousand directions. The action of water upon this saw-mill wheel is a clear demonstration, that the advantage supposed to be obtained by the weight of water in the buckets of wheels, is quite a delusion, as I have sufficiently made manifest in my experiments.

I shall now give a description of a corn mill, said to be the best in the kingdom: we may with truth say it is the best situation in the kingdom; as any thing which can be obtained by the power of water, may be accomplished in this place. This mill is at the seat of Lord Ducie Mortons, in Gloucestershire: it is supplied with water from a large fish pond, which covers several acres of ground; the descent or fall cannot be less than 50 feet perpendicular; the water wheel is 32 feet diameter, and the cog wheel 16, which turns a small wheel about 4 feet diameter, on a vertical axle, upon which is a spur wheel 12 feet diameter, which turns the three trundles. The water wheel is an over-shot one, and the water flows upon it 16 feet below the surface of the pond: the trundles we will suppose 2 feet diameter, as that size is the most advantageous.

First, we may observe, the water wheel being twice the radius of the cog wheel, we lose half the velocity. With balance wheels, suppose the power 400 lb. and the resistance of the corn 200 lb. the proportion will be as  $200:3,14::400:6,28$  the maximum; but here the velocity of the cog wheel will be 3,14 when the water wheel moves with the velocity of 6,28 feet per second; therefore the wheel must move 12,56 feet, to give the velocity of 6,28 to the cog wheel: this cannot be accomplished by any other means than by doubling the power; this I am confident is fact, see Table IV. 3,14 velocity, and the explanation. This is one of the greatest mysteries in mechanics, and ought to be determined by experiments; if it is found to be fact (which I have no doubt of,) it leads mechanics in general into error. I suppose this loss of velocity in this mill, is intended to be regained by the proportion of the small wheel on the upright axle which the cog wheel turns, to the spur wheel which turns the trundles (here the remedy is worse than the disease), the small wheel being in proportion to the spur wheel as 1 to 3, it requires three times the power, and upwards, to move the resistance at the trundles. Hence this train of wheels requires three or four times the power of the balance wheels to equal their effect. Had the cog and water wheel been of the same diameters, and the trundles 2 feet diameter, and a wheel of any convenient diameter upon an up-

right axle, with a double set of cogs, one set for the cog wheel to turn it, the other to turn the trundles; or if this was not convenient, two wheels might have been upon the <sup>of equal diameters</sup> supright axle. With such a train of wheels, the power at the water wheel would have been conveyed to the trundles without any abatement (except friction), and would have met the resistance of the corn at the trundles with its full force.

I make no doubt but I could direct the construction of three corn mills in that situation, one above another, all to be moved by the same stream, and each of them to have nearly, if not quite, as great an effect as the present enormous load of wheels.

I here present the public a new doctrine of mechanics, more especially the extensive and various effects of water, which differs much from the general opinion of all the learned mechanics who have treated on the subject. So different, that it scarcely will be credited; but I beg the public not to censure it too hastily, without proper examination:—facts which may be proved by experiment, are not to be overturned by conjecture.

I have discovered the true means to establish a system of the various effects of water; but to extend it to the utmost of its usefulness, more ex-



periments are necessary, which it is out of my power, in my present situation, to execute, for want of a body or stream of water proper for the purpose. It would complete the utmost of my wishes, for the small remainder of my life (which I cannot expect to be long) to reside in a situation where a proper stream of water might be had for experiments, which I think necessary to complete a true system of water; <sup>and consequently Mechanic power in general;</sup> which I look upon as a most extensive and useful power, far exceeding dead weights, the strength of men or animals. But I have no prospect of its being in my power to choose such a situation, although it might benefit the public more than myself, by the useful discoveries I might make.

In my present situation, what improvements I may make I will communicate them to the world, if my life is prolonged to publish a second edition; therefore, I shall conclude with the same opinion I set out with,—*that the laws of mechanics are the least understood of any useful branch of science whatever.*

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Improvements are necessary, which it is out of my power, in my present situation, to execute, for want of a body or stream of water proper for the purpose. It would complete the ruin of my will, for the small remainder of my life (which I cannot expect to be long) to reside in a situation where a proper stream of water might be had for experiment, which I think necessary to complete a true system of water, which I look upon as a most extensive and useful power, far exceeding what we have at present, the strength of man or animal. But I have no prospect of its being in my power to choose such a situation, although it might benefit the public more than any other, by the useful discovery I might make.

In my present situation, what improvements I may make I will communicate them to the world, if my life is prolonged to publish a second edition; therefore, I shall conclude with the same opinion I for ever wish—*that the laws of mechanics are the most useful and the most extensive branch of science.*

